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DEFECT ESTIMATION FOR WHITE FIR IN THE ROGUE RIVER NATIONAL FOREST

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METRIC CONVERSIONS

1 inch = 2.54 centimeters
1 foot = 30.48 centimeters
1 yard = 0.914 meter
1 cubic foot = 28 316.85 cubic centimeters
1 board foot = 0.0024 cubic meter

DEFECT ESTIMATION FOR WHITE FIR IN THE ROGUE RIVER NATIONAL FOREST

Reference Abstract

Aho, Paul E., and Lewis F. Roth.
1978. Defect estimation for white fir in the Rogue River National Forest. USDA For. Serv. Res. Pap. PNW-240, 18 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A total of 501 white firs with and without indicators of defect were felled, dissected, and studied in 53 widely scattered localities in the Rogue River National Forest. Two methods for estimating defect in white firs are given: (1) Defect percentages of gross merchantable Scribner and International board-foot volumes and cubic-foot volumes are tabulated by d.b.h. and age; defect percentages are added for various indicators. (2) Average length deductions below and above indicators plus flat factors for hidden defect are presented. Multiple regression equations, used to derive the indicator defect percentage tables, are given. Equations excluding age as a variable are included for use when age is unknown. Procedures for developing the estimating equations and testing their precision are discussed.

KEYWORDS: Defect deduction (-merchantable volume, white fir, *Abies concolor*, Indian paint fungus, *Echinodontium tinctorium*, Oregon (Rogue River National Forest).

RESEARCH SUMMARY

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Two methods were developed for estimating the extent of defect in standing white fir trees in southwestern Oregon:

1. Defect percentages of gross merchantable Scribner and International board-foot volumes and cubic-foot volumes are tabulated by d.b.h. and age. When indicators are present, constant defect percentages must be added. Multiple regression equations, used to derive the indicator defect percentage tables, are given. Equations excluding age as a variable are included for use when age is unknown.

2. Length deductions based on average extent of defect below and above various indicators are given along with flat percentage factors for hidden defect.

The first method was considered the most accurate and least subjective. It was determined statistically that a "common" equation for each cubic- and board-foot volume measure could be used to estimate defect in white firs throughout the Rogue River National Forest. The estimating equations were tested for accuracy on an independent sample of trees and were found to predict defect volumes within accepted standards. The first method, defect estimating equations, can be most useful in large scale inventory cruises since it is less subjective and the equations can be used in computer programs compiling inventory data. The second method, average length deductions, may be effectively used by experienced cruisers in timber sale areas.

CONTENTS

INTRODUCTION

The Rogue River National Forest lies on the western slopes of the Cascade Range and on the northern slopes of the Siskiyou Mountains in southwestern Oregon. Total area of the Forest is slightly more than 620,000 acres. Commercial volume of all tree species is estimated to be 3,209 million cubic feet. This timber provides approximately one-third of the raw material for the wood-using industries of the surrounding area. Among 21 species, white fir (*Abies concolor* (Gord. and Glend.) Lindl. accounts for 20 percent of the board-foot volume and 23 percent of the growing stock on this Forest.

White fir is an important component of three timber zones in southwestern Oregon: (1) the Mixed Conifer Zone (various pines, incense-cedar (*Libocedrus decurrens* Torr.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*)) at elevations between 2,000 and 3,500 feet; (2) the White Fir Zone where it occurs in relatively pure stands or in association with Douglas-fir at middle elevations between 2,500 and 4,000 feet; and (3) the Red Fir Zone (*A. magnifica* Murr. var. *shastensis* Lemm.) at elevations between 3,500 and 6,000 feet where it is often the most important associated species (Franklin and Dyrness 1973).

Little cutting occurred in these white fir stands before 1960 because of inaccessibility and excessive defect. Improved markets for white fir have been developed through limited supply of more popular species. More roads have made the white fir available, but increased utilization has not been without problems. Many stands are overmature and defective because of heart rot which weakens trees mechanically, destroys wood volume, and reduces tree vitality. Decay of usable wood, however, is the greatest loss.

Accurate methods for estimating defect in standing white firs are needed for preparation of forest inventories and timber sales. Estimates of gross volume usually are satisfactory, but estimates of net figures are poor because of indadequate allowances for defect (Bruce and Cowlin 1968). Closer utilization of defective stands can be achieved through knowledge of the extent and distribution of decay. Trees with cull can be bucked more accurately and timber sales can be scheduled based on amount of defect in stands.

This paper presents two methods for estimating the extent of defect in living white firs in the Rogue River National Forest, describes the procedure used to develop the most reliable of the two defect-estimating methods, and presents a measure of the precision of the estimating technique when applied to an independent timber sample.

STUDY METHODS

Field Procedure

SAMPLE TREE SELECTION

The study included 501 trees selected in 53 localities in the Rogue River National Forest (table 1, fig. 1). To better study the large and heterogeneous area to which results must apply, we stratified samples among the three broad forest zones previously stated. Areas previously identified on maps by forest personnel as representative of the low elevation mixed conifer, middle elevation white fir, and higher elevation Shasta red fir zones were sampled. In various stands in each zone, an attempt was made to obtain a representative sample of trees with and without defect indicators, including as complete a representation of tree ages and diameters as possible. Appropriate defect indicators for white fir were determined from a preliminary study by Aho in 1966.[1/] These include: sporophores (conks) of *Echinodontium tinctorium* Ell. and Ev. and *Phellinus pini* var. *cancriformans* Larsen, Lomb. & Aho, nom. ined.,[2/] basal and trunk injuries, frost cracks, dead and broken tops, forks, crooks, dead vertical branches, and mistletoe cankers. Normally, trees with at least one indicator were selected from a stand, along with comparable trees without indicators. For various reasons, trees in some age and size classes with specific indicators were difficult to find. This was especially true in the lower elevation Mixed Conifer Zone (table 1).

Table 1--*Number of study trees with defect indicators by forest zone*

Forest zone	Study sample	
	Localities	Trees
Mixed Conifer	8	72
White Fir	22	216
Shasta Red Fir	23	213
Total	53	501

1/ Aho, Paul E. 1968. A progress report on defect in white and red firs on the Rogue River National Forest. 20 p. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

2/ The new variety is planned for publication elsewhere.

Figure 1.--Map of area where investigations were conducted. Numbers indicate study localities.

SAMPLE TREE DISSECTION

The following information was recorded for indicators of defect: type, height from the ground to the bottom of the indicator, and when appropriate for a given indicator, its length, width, depth, diameter, aspect on the tree, position, condition, and age. For cubic volumes, all trees were felled and dissected at 16.3-foot intervals from a 1-foot stump to a 4-inch top d.i.b. (diameter inside bark); they were measured at breast height (d.b.h.) and at the midpoint of the first 16-foot log. Board-foot volumes of trees 11-inch d.b.h. and larger were measured to a variable merchantable top diameter (40 percent of d.b.h., d.i.b.). Other cuts were made so that decay, shake, check, and frost cracks or forks could be measured, infection courts located, and wounds aged. Tree age was determined by a count of rings at stump height.

Office Procedure

CALCULATION OF TREE AND DEFECT VOLUMES

Basic volumes were calculated by an automatic data processing system using a program which computed cubic-foot volumes of logs and decay columns by the Smalian formula. No arbitrary cull rules were used in cubic volume measurement. Board-foot volumes of logs were calculated by the Scribner and International 1/4-inch log scales. Deductions for decay, shake, check, and frost cracks in board feet were made by the squared-defect method. The squared-defect deduction formulas (reduced form) for each log scale were taken from the National Forest Log Scaling Handbook (USDA Forest Service 1964).

DERIVATION AND TESTING OF DEFECT ESTIMATING EQUATIONS

The following procedures were used to generate and test defect estimating formulas:

1. The best estimating variables were determined by multiple regression analysis. Eleven independent and three dependent variables (table 2) were tested in a regression (REX) program which screened all combinations of independent variables to find the "best" regression, i.e., the one with the smallest relative mean-squared-residual (Grosenbaugh 1967, p. 7).

All 501 study trees were used to determine the best combination of variables when the dependent variable was cubic-foot defect percent, but only trees (463) larger than 11-inch d.b.h. were used for analysis of Scribner and International board-foot volumes. The best independent variables for each dependent variable are listed in table 3. Since "forks" was selected as a variable only in the International board-foot estimating equation and its impact on estimates

Table 2--*Number of indicators on 501 white fir trees from three forest zones* 1/

Indicators	Mixed Conifer Zone	White Fir Zone	Shasta Red Fir Zone	All types
None	10	27	38	75
Echinodontium tinctorium conks	16	50	53	119
Phellinus pini var. *cancriformans* conks or cankers	12	32	11	55
Basal injuries	26	49	38	113
Frost cracks	25	61	77	163
Trunk injuries	9	29	18	56
Broken tops	5	22	36	63
Dead tops	4	11	8	23
Crooks	9	32	42	83
Forks	5	22	34	61
Mistletoe trunk cankers	5	16	7	28
Dead vertical branches	2	5	13	20

1/ Many trees had more than one kind of indicator.

Table 3--*Combinations of independent variables (indicators) giving the smallest relative mean squared residual with each dependent variable tested in multivariate regression analysis*

Independent variables	Dependent variables 1/		
	Cubic-foot defect percent	Board-foot defect percent	
		Scribner	International
Tree d.b.h.	X	X	X
Tree age	X	X	X
Echinodontium tinctorium conks	X	X	X
Phellinus pini var. *cancriformans* conks or cankers	X	X	X
Basal injuries	X	X	X
Frost cracks	--	X	X
Trunk injuries	X	X	X
Broken or dead tops	X	--	--
Crooks	X	--	--
Forks	X	--	X
Mistletoe cankers	--	--	--
Dead vertical branches	--	--	--

1/ X's indicate independent variables that can be used with each dependent variable to get the "best" regression estimating equations. Dashes indicate the variables having little or no effect in increasing precision of the estimating equations.

of decay percents was so small, it was deleted.

2. From only the best variables, estimating equations were calculated for each forest zone. The equations for each volume measurement for the three zones were tested by covariance analysis (RECOR) for differences among equations.[3/] Significant differences were not found for either board-foot measurement. There were no significant differences among regression surfaces or elevations; thus, "common" equations were selected for each board-foot measure to make defect estimates in all forest zones (Snedecor and Cochran 1967, chapter 14).

Regression surfaces among cubic-foot estimating equations for each forest zone were significantly different at the 5-percent level of probability; however, because the statistical evidence of differences in estimating equations was slight and since there is a practical problem of identifying forest zones in the field, a "common" equation was selected for use in cubic volume defect estimations also.

3. The common estimating equations for each volume measurement were tested on an independent sample of 146 white firs felled, dissected, and measured in 1966 (see footnote 1, page 2) by the methods used in the present study. Estimated defect percents calculated for each of those 146 trees by the equations developed here were compared with those measured for each tree in 1966 by chi-square (Freese 1960). An index of accuracy of 15 percent was chosen for the cubic-foot test and 25 percent for the board-foot. The test of differences between actual and estimated defect percents at the 5-percent probability level was met for each volume measurement.

The intent of defect prediction schemes is to accurately determine net volume of a sample of trees by estimating the total sound volume of individual trees. To see if the equations satisfied this criterion, we computed estimated cubic- and board-foot defect volumes for the 1966 sample trees by applying the estimated defect percents to tree volumes. Estimated defect volumes for trees were totaled, converted to percents of total merchantable volumes of the sample trees, and compared with the measured (actual) defect volumes. Estimated defect in cubic- and board-foot volumes was within 1 percent of the actual defect for the entire sample. Since accepted standards of precision for determining net volumes of cruise trees is 5 to 10 percent (Bruce and Cowlin 1968), the estimating equations acceptably predicted defect volume in this sample and thus provide further support for use of common equations wherever white fir occurs in the Rogue River National Forest.

[3/] Pacific Northwest Forest and Range Experiment Station. 1970. Program RECOR. Library of Computer Programs, Portland, Oreg.

DEFINITION AND DESCRIPTION OF DEFECT AND INDICATORS

Defect.--When expressed as cubic volume, defect includes only decay; for board-foot deductions defect includes decay, shake, check, and frost cracks. Crook, sweep, breakage in felling, and missing parts of trees, such as broken tops, are not deducted in either measurement.

Defect percentages.--Deductions include the appropriate defect within the tree from a 1-foot stump height to a 4-inch top d.i.b. for cubic volume, and to the point where stem diameter inside bark equals 40 percent of tree d.b.h. for Scribner and International board-foot volumes. No arbitrary log cull rules were used in deductions for cubic-foot defect. In board feet, a log was considered totally defective if it was less than one-third sound.

Defect indicators.--These are of two general types: (1) signs of decay fungi, such as conks or punky knots, and (2) wounds or scars indicating possible infection courts for decay fungi. These include basal and trunk injuries, frost cracks, crooks, forks, mistletoe cankers, dead and broken tops, and dead vertical branches. Frost cracks are board-foot defects even if they are not associated with decay.

Conks.--These are certain signs of decay. The only fungi found consistently producing sporophores on white firs in this study were *Echinodontium tinctorium* and *Phellinus pini* var. *cancriformans. Echinodontium tinctorium* sporophores (fig. 2) were the most significant defect indicators because considerable defect usually is associated with them (fig. 3).

Figure 2.--Conks of the Indian paint fungus, Echinodontium tinctorium *on white fir.*

Figure 3.--Sections of a white fir tree at 32, 49, 65, 81, and 98 feet illustrate extent of Echinodontium tinctorium *decay.*

They are generally seen protruding from the trunk at the base of branch stubs (fig. 2); but they may be attached at the junction of live branches as well and may be overlooked in the living crown.

On thin-barked host species, *P. pini* var. *cancriformans* invades the sapwood from the heartwood and often locally kills the cambium, thereby causing cankered areas (fig. 4). This behavior is particularly common in true firs. Sporophores often are profusely scattered over the canker surface (fig. 5). Occasionally cankers are caused when no conks are present (fig. 6). Defect deductions for these cankers

Figure 4.--Decay and cankers caused by Phellinus pini *var.* cancriformans.

*Figure 5.--*Phellinus pini *var.* cancriformans *conks on a canker at the base of a white fir.*

*Figure 6.--*Phellinus pini *var.* cancriformans *caused canker without conks.*

are the same as for cankers with sporophores.

At certain times of the year, *Pholiota* sp. and *Hericium abietis* (Weir ex Hubert) K. Harrison may produce sporophores on or near injuries. Deductions for these should be based on the type of injury rather than on the sporophores.

Basal injuries.--These include open or closed wounds in contact with the ground. Basal scars may be caused by fires (fig. 7), falling trees, or other mechanical injuries and are one of the most important defect indicators. They are sometimes inconspicuous and easily overlooked, resulting in significant error in volume estimates. With the exception of frost cracks, recent injuries (basal and trunk wounds and dead and broken tops less than 10 years old) should be ignored since little or no defect is associated with them.

Figure 7.--A basal fire injury on a white fir.

Trunk injuries.--They include open or closed wounds more than 1 foot long and more than 10 years old which are located below the merchantable top diameter but are not in contact with the ground (fig.8). Trunk injuries include wounds from falling trees, lightning, animal damage, and logging.

Figure 8.--A trunk injury on a white fir probably caused by a falling tree.

Frost cracks.--These open scars or seams are probably caused by freezing (fig. 9). They are particularly common in white firs and probably are associated with excessive moisture (wetwood). Often, trees with bleeding cracks will also bear Indian paint fungus conks higher on their trunks. The decay associated with the conks will not usually extend into the wetwood and frost crack area. Frost cracks, shake, and wetwood occur together (fig. 10). Trees with frost cracks

Figure 9.--A basal frost crack in a white fir.

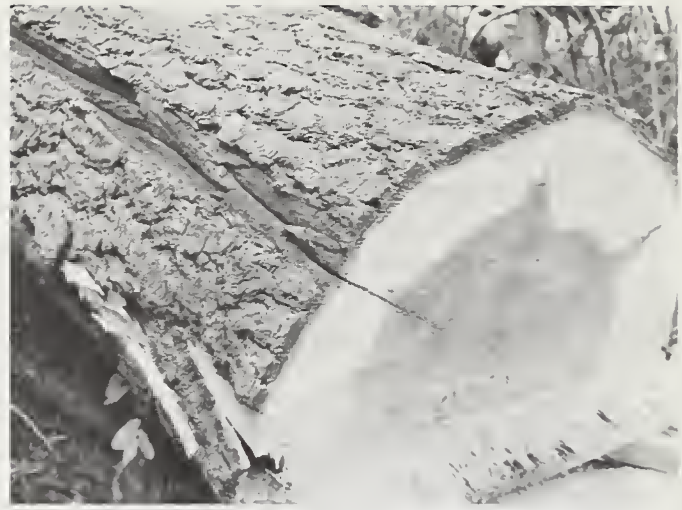

Figure 10.--Cross-section at the base of a white fir showing wetwood, frost cracks, and shake.

as their only defect indicator generally do not have decay associated with the cracks; thus, there is no cubic volume loss. There will be board-foot defect, however, because of the cracks, check, and shake.

Top injuries.--Included are tops broken by wind, ice, or snow (fig. 11) within the merchantable portion of the tree and spike tops resulting from insects, rust fungi, dwarf mistletoe, animals, or unknown causes (fig. 12). Tops that

Figure 11.--A white fir with a broken top within the merchantable portion of the bole.

Figure 12.--A white fir with a dead top caused by bark beetles.

are dead or are broken above the merchantable limit and recent top damage are not defect indicators.

Crooks.--These are sudden bends in the merchantable bole. They may result when young trees bend under ice, snow, or animals; in older trees, they may result from breaks or leader death high in the tree. The former, since there is no break, are free of decay whereas the latter often become infected (fig. 13). If the diameter at the crook is less than about 10 inches, the decay will usually extend downward only.

Forks.--Forked trees result when two or more lateral branches succeed in replacing a dead or broken leader (fig. 14).

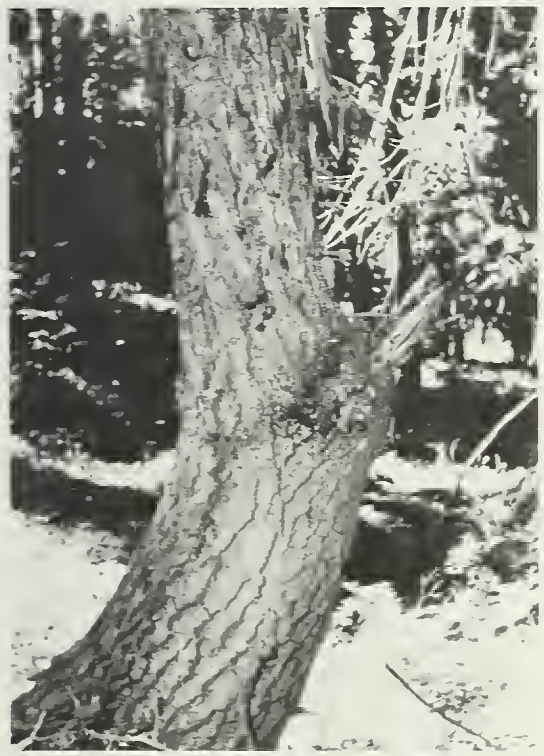

Figure 13.--A white fir with a crook or "pistol butt" near the ground. An old, broken-off leader usually indicates that decay is present.

Figure 14.--A forked white fir.

Dead vertical branches.--These may be old leaders or lateral branches that died after unsuccessful competition with a stronger leader (fig. 15). When dead vertical branches are associated with a crook, decay is usually present.

Dwarf mistletoe infection.--*Arceuthobium abietinum* Engelm. ex Munz f. sp. *concoloris* Hawksworth & Wiens often results in pronounced swellings or cankers on the bole or large branches (fig. 16). Cankers with tight bark (fig. 16) usually do not admit decay fungi. When the bark on these cankers sloughs off, exposing wood (fig. 17), infection by decay fungi can occur; however, decay generally does not extend beyond the limits of the swelling.

Figure 15.--A dead vertical branch on a white fir. If a crook occurs, decay is usually present.

Figure 16.--A dwarf mistletoe trunk canker on a white fir. The bark is still tight; thus, there will be no associated decay.

Figure 17.--Open dwarf mistletoe trunk canker on a white fir. Decay may be associated with these indicators, but it seldom extends beyond the limits of the swelling.

ESTIMATION OF DEFECT IN WHITE FIR

Two methods are presented here for estimating the extent of defect in standing white fir trees in the Rogue River National Forest, and they may be applicable in all of southwestern Oregon:

1. Indicator defect factors, developed by multiple regression analysis, are given as percentages of gross merchantable Scribner and International board-foot volumes and cubic-foot volumes.

2. Average deductions for length below and above indicators are presented along with flat percentage factors for hidden defect.

Although both types of defect factors may be fairly accurate with small samples, or even single trees, results will be more accurate when the factors are applied to larger numbers of trees. The two methods cannot be used together in a given timber cruise.

Indicator-Defect Percentage Factors

Defect percentages can be calculated from table 4 (Scribner), table 5 (International), and table 6 (cubic).

Table 4--*Defect in percent*[1/] *of gross merchantable Scribner board-foot volume from a 1-foot stump height to a variable (Girard) top d.i.b. for white fir trees by age and d.b.h.*[2/]

0.b.h. (inches)	Tree age (years)																	
	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
11	3	5	7	9	11	13	15	17	19	22	24	26	28	30	32	34	36	38
12	2	4	6	8	10	12	15	17	19	21	23	25	27	29	31	33	35	38
13	1	3	5	7	10	12	14	16	18	20	22	24	26	28	31	33	35	37
14	0	3	5	7	9	11	13	15	17	19	21	23	26	28	30	32	34	36
15	0	2	4	6	8	10	12	14	16	19	21	23	25	27	29	31	33	35
16	0	1	3	5	7	9	11	14	16	18	20	22	24	26	28	30	32	34
17	0	0	2	4	7	9	11	13	15	17	19	21	23	25	27	30	32	34
18	0	0	2	4	6	8	10	12	14	16	18	20	23	25	27	29	31	33
19	0	0	1	3	5	7	9	11	13	15	18	20	22	24	26	28	30	32
20	0	0	0	2	4	6	8	11	13	15	17	19	21	23	25	27	29	31
21	0	0	0	1	3	6	8	10	12	14	16	18	20	22	24	26	29	31
22	0	0	0	1	3	5	7	9	11	13	15	17	19	22	24	26	28	30
23	0	0	0	0	2	4	6	8	10	12	14	17	19	21	23	25	27	29
24	0	0	0	0	1	3	5	7	10	12	14	16	18	20	22	24	26	28
25	0	0	0	0	0	3	5	7	9	11	13	15	17	19	21	23	26	28
26	0	0	0	0	0	2	4	6	8	10	12	14	16	18	21	23	25	27
27	0	0	0	0	0	1	3	5	7	9	11	14	16	18	20	22	24	26
28	0	0	0	0	0	0	2	4	6	9	11	13	15	17	19	21	23	25
29	0	0	0	0	0	0	2	4	6	8	10	12	14	16	18	20	22	25
30	0	0	0	0	0	0	1	3	5	7	9	11	13	15	18	20	22	24
31	0	0	0	0	0	0	0	2	4	6	8	10	13	15	17	19	21	23
32	0	0	0	0	0	0	0	1	3	6	8	10	12	14	16	18	20	22
33	0	0	0	0	0	0	0	1	3	5	7	9	11	13	15	17	19	21
34	0	0	0	0	0	0	0	0	2	4	6	8	10	12	14	17	19	21
35	0	0	0	0	0	0	0	0	1	3	5	7	10	12	14	16	18	20
36	0	0	0	0	0	0	0	0	0	2	5	7	9	11	13	15	17	19
37	0	0	0	0	0	0	0	0	0	2	4	6	8	10	12	14	16	18
38	0	0	0	0	0	0	0	0	0	1	3	5	7	9	11	13	16	18
39	0	0	0	0	0	0	0	0	0	0	2	4	6	9	11	13	15	17
40	0	0	0	0	0	0	0	0	0	0	1	4	6	8	10	12	14	16

1/ These constant defect percentages must be added for each type of indicator present on a sample tree: *Echinodontium tinctorium* conks, 49; *Phellinus pini* var. *cancriformans* conks or cankers, 21; basal injuries, 22; trunk injuries, 7; and frost cracks, 6.

2/ Oerived by the common equation: $P_b = 4.886 + 0.105A - 0.765 + 49.395C + 21.4550 + 21.904E + 7.407F + 6.097G$; where: P_b = percent of gross merchantable Scribner board-foot volume that is cull; A = tree age in years; 8 = tree d.b.h. in inches; C = 1 if one or more *Echinodontium tinctorium* conks are present, 0 if no conks; 0 = 1 if one or more *Phellinus pini* var. *cancriformans* conks or cankers are present, 0 if no conks or cankers; E = 1 if one or more basal injuries are present, 0 if no basal injuries; F = 1 if one or more trunk injuries are present, 0 if no trunk injuries; G = 1 if one or more frost cracks are present, 0 if no frost cracks.

The coefficient of determination (R^2) for this equation is 0.645.

Table 5--*Defect in percent*[1/] *of gross merchantable International board-foot volume from a 1-foot stump height to a variable (Girard) top d.i.b. for white fir trees by age and d.b.h.*[2/]

D.b.h. (inches)	Tree age (years)																	
	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
11	1	4	6	8	10	12	14	16	19	21	23	25	27	29	31	34	36	38
12	1	3	5	7	9	11	14	16	18	20	22	24	26	29	31	33	35	37
13	0	2	4	6	9	11	13	15	17	19	21	24	26	28	30	32	34	36
14	0	1	4	6	8	10	12	14	16	19	21	23	25	27	29	31	34	36
15	0	1	3	5	7	9	11	14	16	18	20	22	24	26	29	31	33	35
16	0	0	2	4	6	9	11	13	15	17	19	21	24	26	28	30	32	34
17	0	0	1	4	6	8	10	12	14	16	19	21	23	25	27	29	31	34
18	0	0	1	3	5	7	9	11	14	16	18	20	22	24	26	28	31	33
19	0	0	0	2	4	6	8	11	13	15	17	19	21	23	26	28	30	32
20	0	0	0	1	3	6	8	10	12	14	16	18	21	23	25	27	29	31
21	0	0	0	1	3	5	7	9	11	13	16	18	20	22	24	26	28	31
22	0	0	0	0	2	4	6	8	11	13	15	17	19	21	23	26	28	30
23	0	0	0	0	1	3	6	8	10	12	14	16	18	21	23	25	27	29
24	0	0	0	0	1	3	5	7	9	11	13	16	18	20	22	24	26	28
25	0	0	0	0	0	2	4	6	8	11	13	15	17	19	21	23	26	28
26	0	0	0	0	0	1	3	6	8	10	12	14	16	18	21	23	25	27
27	0	0	0	0	0	0	3	5	7	9	11	13	15	18	20	22	24	26
28	0	0	0	0	0	0	2	4	6	8	10	13	15	17	19	21	23	25
29	0	0	0	0	0	0	1	3	5	8	10	12	14	16	18	20	23	25
30	0	0	0	0	0	0	0	3	5	7	9	11	13	15	18	20	22	24
31	0	0	0	0	0	0	0	2	4	6	8	10	13	15	17	19	21	23
32	0	0	0	0	0	0	0	1	3	5	8	10	12	14	16	18	20	23
33	0	0	0	0	0	0	0	0	3	5	7	9	11	13	15	18	20	22
34	0	0	0	0	0	0	0	0	2	4	6	8	10	13	15	17	19	21
35	0	0	0	0	0	0	0	0	1	3	5	7	10	12	14	16	18	20
36	0	0	0	0	0	0	0	0	0	2	5	7	9	11	13	15	17	20
37	0	0	0	0	0	0	0	0	0	2	4	6	8	10	12	15	17	19
38	0	0	0	0	0	0	0	0	0	1	3	5	7	10	12	14	16	18
39	0	0	0	0	0	0	0	0	0	0	2	5	7	9	11	13	15	17
40	0	0	0	0	0	0	0	0	0	0	2	4	6	8	10	12	15	17

[1/] These constant defect percentages must be added for each type of indicator present on a sample tree: *Echinodontium tinctorium* conks, 46; *Phellinus pini* var. *cancriformans* conks or cankers, 20; basal injuries, 21; trunk injuries, 7; and frost cracks, 6.

[2/] Derived by the common equation: $P_b = 3.104 + 0.107A - 0.731B + 46.435C + 19.810D + 20.898E + 6.776F + 5.747G$;
where: P_b = percent of gross merchantable International board-foot volume that is cull; A = tree age in years; B = tree d.b.h. in inches; C = 1 if one or more *Echinodontium tinctorium* conks are present, 0 if no conks; D = 1 if one or more *Phellinus pini* var. *cancriformans* conks or cankers are present, 0 if no conks or cankers; E = 1 if one or more basal injuries are present, 0 if no basal injuries; F = 1 if one or more trunk injuries are present, 0 if no trunk injuries; G = 1 if one or more frost cracks are present, 0 if no frost cracks.

The coefficient of determination (R^2) for this equation is 0.629.

Table 6--*Defect in percent*[1/] *of gross merchantable cubic-foot volume from a 1-foot stump height to a 4-inch top d.i.b. for white fir trees by age and d.b.h.*[2/]

D.b.h. (inches)	Tree age (years)																	
	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
5	2	3	4	4	5	6	7	8	9	10	10	11	12	13	14	15	16	16
6	2	2	3	4	5	6	7	8	8	9	10	11	12	13	14	14	15	16
7	1	2	3	4	5	6	6	7	8	9	10	11	12	12	13	14	15	16
8	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	14	15	16
9	1	1	2	3	4	5	6	7	8	8	9	10	11	12	13	14	14	15
10	0	1	2	3	4	5	5	6	7	8	9	10	11	11	12	13	14	15
11	0	1	2	3	3	4	5	6	7	8	9	9	10	11	12	13	14	15
12	0	1	1	2	3	4	5	6	7	7	8	9	10	11	12	13	13	14
13	0	0	1	2	3	4	5	5	6	7	8	9	10	11	11	12	13	14
14	0	0	1	2	3	3	4	5	6	7	8	9	9	10	11	12	13	14
15	0	0	0	1	2	3	4	5	6	6	7	8	9	10	11	12	13	13
16	0	0	0	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13
17	0	0	0	1	2	2	3	4	5	6	7	8	8	9	10	11	12	13
18	0	0	0	0	1	2	3	4	5	6	6	7	8	9	10	11	12	12
19	0	0	0	0	1	2	3	4	4	5	6	7	8	9	10	10	11	12
20	0	0	0	0	1	2	2	3	4	5	6	7	8	8	9	10	11	12
21	0	0	0	0	0	1	2	3	4	5	5	6	7	8	9	10	11	12
22	0	0	0	0	0	1	2	3	3	4	5	6	7	8	9	9	10	11
23	0	0	0	0	0	1	1	2	3	4	5	6	7	7	8	9	10	11
24	0	0	0	0	0	0	1	2	3	4	5	5	6	7	8	9	10	11
25	0	0	0	0	0	0	1	2	3	3	4	5	6	7	8	9	9	10
26	0	0	0	0	0	0	0	1	2	3	4	5	6	7	7	8	9	10
27	0	0	0	0	0	0	0	1	2	3	4	4	5	6	7	8	9	10
28	0	0	0	0	0	0	0	1	2	2	3	4	5	6	7	8	8	9
29	0	0	0	0	0	0	0	0	1	2	3	4	5	6	6	7	8	9
30	0	0	0	0	0	0	0	0	1	2	3	4	4	5	6	7	8	9
31	0	0	0	0	0	0	0	0	1	2	2	3	4	5	6	7	8	8
32	0	0	0	0	0	0	0	0	0	1	2	3	4	5	6	6	7	8
33	0	0	0	0	0	0	0	0	0	1	2	3	3	4	5	6	7	8
34	0	0	0	0	0	0	0	0	0	1	1	2	3	4	5	6	7	7
35	0	0	0	0	0	0	0	0	0	0	1	2	3	4	5	5	6	7
36	0	0	0	0	0	0	0	0	0	0	1	2	3	3	4	5	6	7
37	0	0	0	0	0	0	0	0	0	0	1	1	2	3	4	5	6	7
38	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	5	5	6
39	0	0	0	0	0	0	0	0	0	0	0	1	2	2	3	4	5	6
40	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	5	6

[1/] These constant defect percentages must be added for each type of indicator present on a sample tree: *Echinodontium tinctorium* conks, 26; *Phellinus pini* var. *cancriformans* conks or cankers, 10; basal injuries, 9; trunk injuries, 4; crooks, 2; forks, 1; and dead or broken tops, 2.

[2/] Derived by the common equation: $P_c = 0.837 + 0.043A - 0.311B + 25.518C + 9.876D + 9.175E + 4.221F + 2.108G + 1.238H + 2.390I$;
where: P_c = percent of gross merchantable cubic-foot volume that is cull; A = tree age in years; B = tree d.b.h. in inches; C = 1 if one or more *Echinodontium tinctorium* conks are present, 0 if no conks; D = 1 if one or more *Phellinus pini* var. *cancriformans* conks or cankers are present. 0 if no conks or cankers; E = 1 if one or more basal injuries are present, 0 if no basal injuries; F = 1 if one or more trunk injuries are present, 0 if no trunk injuries; G = 1 if one or more dead or broken tops are present, 0 if no dead or broken tops; H = 1 if one or more forks are present, 0 if no forks; I = 1 if one or more crooks are present, 0 if no crooks.

The coefficient of determination (R^2) for this equation is 0.617.

Volume defect factors were derived from the common (weighted average of the estimating equations for the three forest cover types) equations footnoted in tables 4-6. For ease in presentation, the equations were solved and tabulated for d.b.h. and age only. Constants are included to be added for each type of defect indicator present (tables 4-6). Equations without tree age as a variable are included in table 7 for use when ages are not available.

Table 7--*Coefficients of regression equations*[1] *for estimating cubic- and board-foot defect percents in individual white firs*

Volume measure	Number of trees	Regression coefficients for independent variables[2]									Y-intercept	R^2
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9		
Cubic feet	501	-0.172	26.711	8.977	9.478	3.810	--	2.338	1.191	2.020	5.399	0.598
Board feet, Scribner rule	463	-.416	52.428	19.350	22.600	6.476	6.382	--	--	--	15.459	.617
Board feet, International 1/4-inch rule	463	-.374	49.540	17.655	21.610	5.823	6.039	--	--	--	13.929	.597

[1] Based on the weighted average of equations for trees from the three white fir forest cover types.

[2] X_1 = tree d.b.h. in inches.
X_2 = 1 if one or more *Echinodontium tinctorium* conks present; 0 if no conks present.
X_3 = 1 if one or more *Phellinus pini* var. *cancriformans* cankers or conks present; 0 if no cankers or conks present.
X_4 = 1 if one or more basal injuries more than 10 years old present; 0 if no basal injuries present.
X_5 = 1 if one or more trunk injuries more than 10 years old and longer than 1 foot present; 0 if no trunk injuries present.
X_6 = 1 if one or more frost cracks present; 0 if no frost cracks present.
X_7 = 1 if dead or broken top present; 0 if no dead or broken top present.
X_8 = 1 if one or more forks present; 0 if no forks present.
X_9 = 1 if one or more crooks present; 0 if no crooks present.
R^2 = Coefficient of determination or the percent of variation explained by the variables in the equations.

Solving the equations for some combinations of d.b.h., age, and indicators for a tree can result in defect percentages of less than zero or greater than 100 percent. In these cases, if the equations are used in a computer program, the program should set the percentages at zero or 100 percent.

APPLICATION OF DEFECT PERCENTAGE FACTORS

Accurate application of defect percentages in tables 4 to 6 requires familiarity both with the definitions of cubic- and board-foot defect and with which indicators are reliably associated with each type of volume measurement. Sample trees must be carefully examined, the presence of meaningful indicators noted, and d.b.h. and age measured. When age is not known, the appropriate equation in table 7 can be used to calculate defect percent.

A 16-inch, 140-year-old white fir without indicators would have defect deductions of 7 percent of its gross merchantable Scribner board-foot volume (table 4), 6 percent of its International board-foot volume (table 5), and 2 percent of its cubic-foot volume (table 6). If, in addition, the tree has an *E. tinctorium* conk, the following constants for this indicator must be added to the defect percents to obtain the proper deduction: 26 percent for cubic-foot volume, 49 percent for Scribner board-foot volume, and 46 percent for International board-foot volume. Thus, the total defect percents for the above tree would be 28, 56, and 52 percent for cubic volume and for Scribner and

International board-foot volumes, respectively. If other defect indicators were present, additional appropriate constants would be necessary to obtain the full deduction for the tree.

Indicator Length Deductions and Flat Percentage Factors For Hidden Defect

It is customary in certain types of timber cruises to determine net tree volumes by deducting portions of trees below and above visible indications of defect. Therefore, average length deductions are presented for the more reliable indicators on white fir (table 8). In many instances, decay columns ran into the roots, into another decay column in the bole, or into a missing top. Because of such interference, some decay columns were unusable in determining average length deductions (note difference between the number of trees with indicators and the number of indicators used to determine average deductions in table 8).

Table 8--*Length deductions for the more reliable indicators of defect on white firs in the Rogue River National Forest*

Type of indicator	Trees with indicators	Data for deduction below bottom of indicator				Data for deduction above top of indicator			
		Average length of deduction	Indicators used to compute average[1/]	Range	Indicators without deductions[2/]	Average length of deduction	Indicators used to compute average[1/]	Range	Indicators without deductions[2/]
	Number	Feet	Number	Feet	Number	Feet	Number	Feet	Number
Echinodontium tinctorium conks	119	11	91	0-60	1	20	111	0-80	1
Phellinus pini var. *cancriformans* conks or cankers	55	4	27	0-14	9	6	46	0-28	14
Basal injuries more than 10 years old	105	--	--	--	--	9	94	0-48	42
Trunk injuries more than 10 years old and 1 foot long	53	1	46	0-9	36	2	50	0-17	40
Crooks	82	2	74	0-19	57	1	74	0-11	67
Forks	60	1	57	0-12	41	2	54	0-25	49
Top injuries more than 10 years old	85	3	83	0-18	35	--	--	--	--

1/ Does not include indicators with decay columns that ran into decay columns associated with other indicators nor those that ran into the ground or a missing top.

2/ Number of indicators that had either no associated defect or such a small amount that no deduction was necessary. Many basal and trunk injuries, for instance, had considerable volumes of defect within the limits of the injuries, but little or none below or above.

The range of length deductions for a given indicator varies considerably. For instance, length deductions below and above *E. tinctorium* conks varied from 0 to 60 feet below the lowest conks and 0 to 80 feet above the highest (table 8). Moreover, except for *E. tinctorium* conks, many of each indicator type had no associated defect (table 8). Therefore, the average deduction for a given indicator class should be applied to each individual of that class encountered.

APPLICATION OF LENGTH DEDUCTIONS AND FLAT PERCENTAGE FACTORS FOR HIDDEN DEFECT

Length deductions in table 8 are only for the more reliable indicators of defect in white firs. Again, as with

the defect percentages, length deductions are averages, so they cannot be expected to be accurate for individual trees or even small groups of trees. The minimum number of trees needed for accurate defect volume estimates has not been determined; it will vary from area to area because the percentage of trees with certain types of indicators will also vary.

Application of the length deductions is relatively easy. If a tree has a series of *E. tinctorium* conks and a broken top, deduct the portion of the tree 11 feet below the lowest conk to 20 feet above the highest and the 3 feet below the broken top (table 8). Where there are two or more different indicators in one segment of the tree, use the indicator with the longest length deduction. For instance, if there is a crook within a series of *E. tinctorium* conks, ignore the crook and base the deduction on the sporophores.

Total net cubic-foot and Scribner and International board-foot volumes must be reduced by 0.4, 5.2, and 4.2 percent, respectively, to account for hidden defect (table 9).

Table 9--*Cubic- and board-foot hidden defect percentages by d.b.h. classes for white fir on the Rogue River National Forest*[1]

D.b.h. class	Basis	Average d.b.h.	Average age	Hidden defect percentages		
				Cubic feet	Board feet	
					Scribner rule	International 1/4-inch rule
Inches	Number	Inches	Years	Percent		
5.0-10.9	38	8.5	141	0.2	--	--
11.0-14.9	38	13.2	158	.5	2.9	2.6
15.0-18.9	94	17.1	164	.4	4.1	3.5
19.0-22.9	86	20.9	179	.9	5.9	4.9
23.0-26.9	77	24.7	185	.3	4.4	3.6
27.0-30.9	87	29.0	196	.1	4.4	3.8
31.0-34.9	44	32.7	225	.2	3.6	2.8
35.0-38.9	19	37.0	223	1.2	12.3	9.5
39.0+	18	41.7	269	.8	5.6	4.7
Total or average	501	23.0	185	.4	5.2	4.2

[1] Hidden defect percentages in this table should be used only with indicator length deductions in table 8.

In summary, net volumes on sample trees are calculated by use of the indicator-length deduction factors; net tree volumes are totaled. The appropriate flat percentage factor for hidden defect is applied to the total net sample volume. This gives the net sound volume of the sample, minus deductions for sweep, breakage in logging, and missing parts of trees such as broken tops.

CONCLUSIONS

Two methods for estimating defects in standing white firs are presented. Either system may be used separately to determine net volumes of sample trees from timber cruises; however, each method may be advantageously used in given situations. For instance, the indicator-length deduction factors may be used effectively by experienced cruisers in timber sale surveys which are usually local.

The indicator-defect percentage factors may be most effectively used to develop inventory data for relatively large areas--for southwestern Oregon or working circles in the Rogue River National Forest, for instance. Results from tests of the estimating equations indicate that they may also accurately predict defect volumes of small numbers of trees from local areas, although their effectiveness would probably increase with larger numbers of trees. Since it is only necessary to indicate the presence of various indicators they are less subjective than the indicator-length deduction factors where the cruiser must estimate which portions of trees are defective. Thus, the indicator-defect percentage method could be more accurately applied by inexperienced personnel who are often used to cruise timber (Bruce and Cowlin 1968).

The estimating equations also lend themselves well to computer programs now used by many forest management agencies to develop inventory data.

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Two methods are given for estimating the extent of defect in white firs in the Rogue River National Forest. (1) Defect percentages of gross merchantable Scribner and International board-foot volumes and cubic-foot volumes are tabulated by d.b.h. and age; constant defect percentages must be added for various indicators. (2) Average length deductions below and above indicators plus flat factors for hidden defect are also presented.

KEYWORDS: Defect deduction (-merchantable volume, white fir, *Abies concolor*, Indian paint fungus, *Echinodontium tinctorium*, Oregon (Rogue River National Forest).

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